Lecture 23. Net radiative heating/cooling rates.

Objectives:

1. Solar heating rates.
2. Net radiative heating/cooling rates in a cloudy atmosphere.
3. Net radiative heating/cooling rates in an aerosol-laden atmosphere.
4. Global distribution of radiative heating/cooling rates.

Recommended reading:

L02: 4.7, 3.5, 8.2.4

Quijano, A.L., I. N. Sokolik, O.B. Toon, "Radiative heating rates and direct radiative forcing by mineral dust in cloudy atmospheric conditions", JGR, V. 105, D10, pp. 12,207-12,219, 2000.

1. Solar heating rates.

No emission in solar => no cooling, only heating due to absorption

Solar net flux is often defined as (e.g., L02)

$$F_{net}(z) = F^{\downarrow}(z) - F^{\uparrow}(z) \qquad [23.1]$$

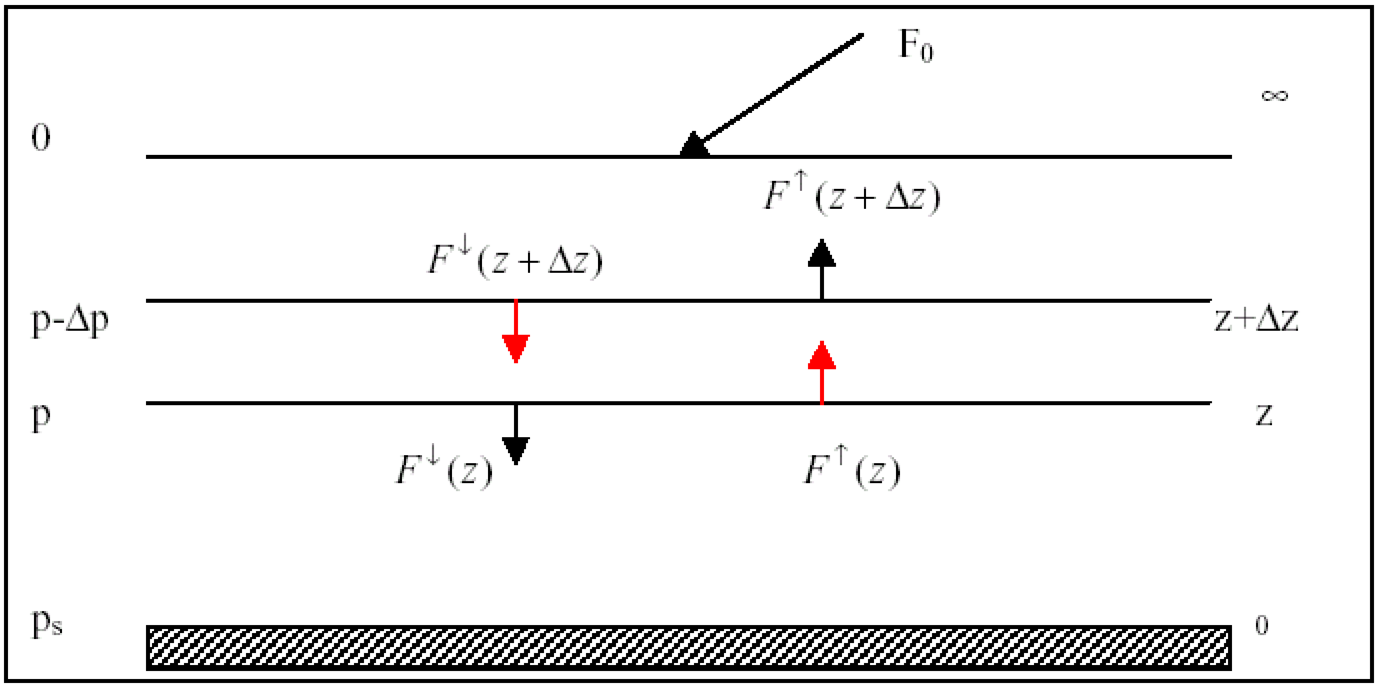
so the flux divergence is $\Delta F = F(z) - F(z + \Delta z)$

[23.2]

$$\left(\frac{dT}{dt}\right)_{solar} = -\frac{1}{c_p \rho}\frac{dF_{net}}{dz} = \frac{g}{c_p}\frac{dF_{net}}{dp}$$

$$F_{net}(z) = F^{\downarrow}(z) - F^{\uparrow}(z)$$

$$\Delta F = F(z) - F(z + \Delta z)$$



Instantaneous heating/cooling rates – rates calculated for a given moment of time (e.g., for solar heating is at a given sun angle)

Hourly, diurnally, monthly and annually averaged rates are also used.

2. Net radiative heating/cooling rates in an cloudy atmosphere.

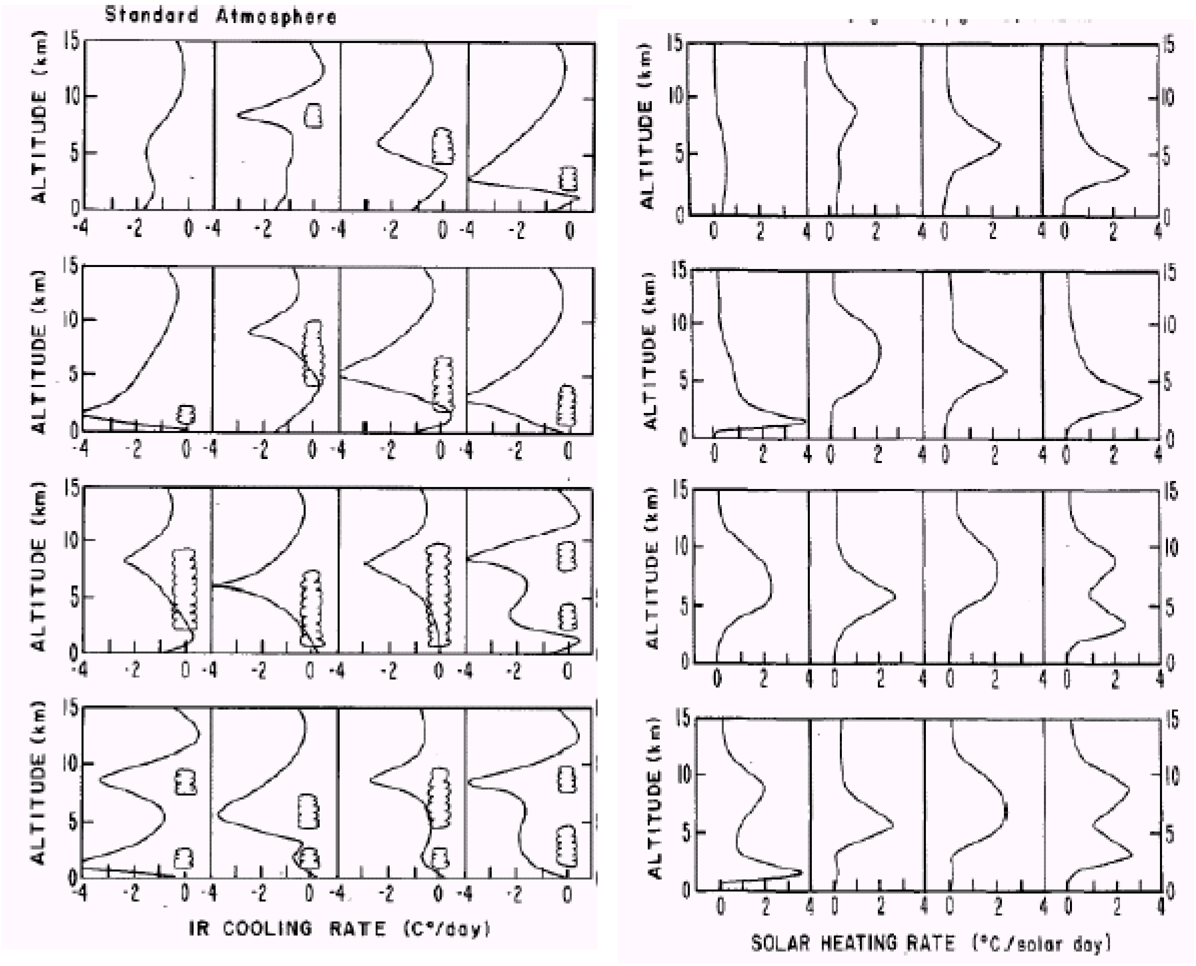


Figure 23.1 IR and solar heating/cooling rate profiles for clear and various cloudy atmospheres. 100% cloud cover is assumed. Solar heating rates were calculated for a solar constant of 1360 W/m^2, surface albedo of 0.15, cosine of solar zenith angle 0.5 and solar time duration of 12 hours (modified from Liou and Zheng, 1984).

↖Cirrus clouds

Main features :

- Strong IR cooling above a cirrus cloud and strong warming below.
- Maximum of solar heating at the top of a cirrus cloud.

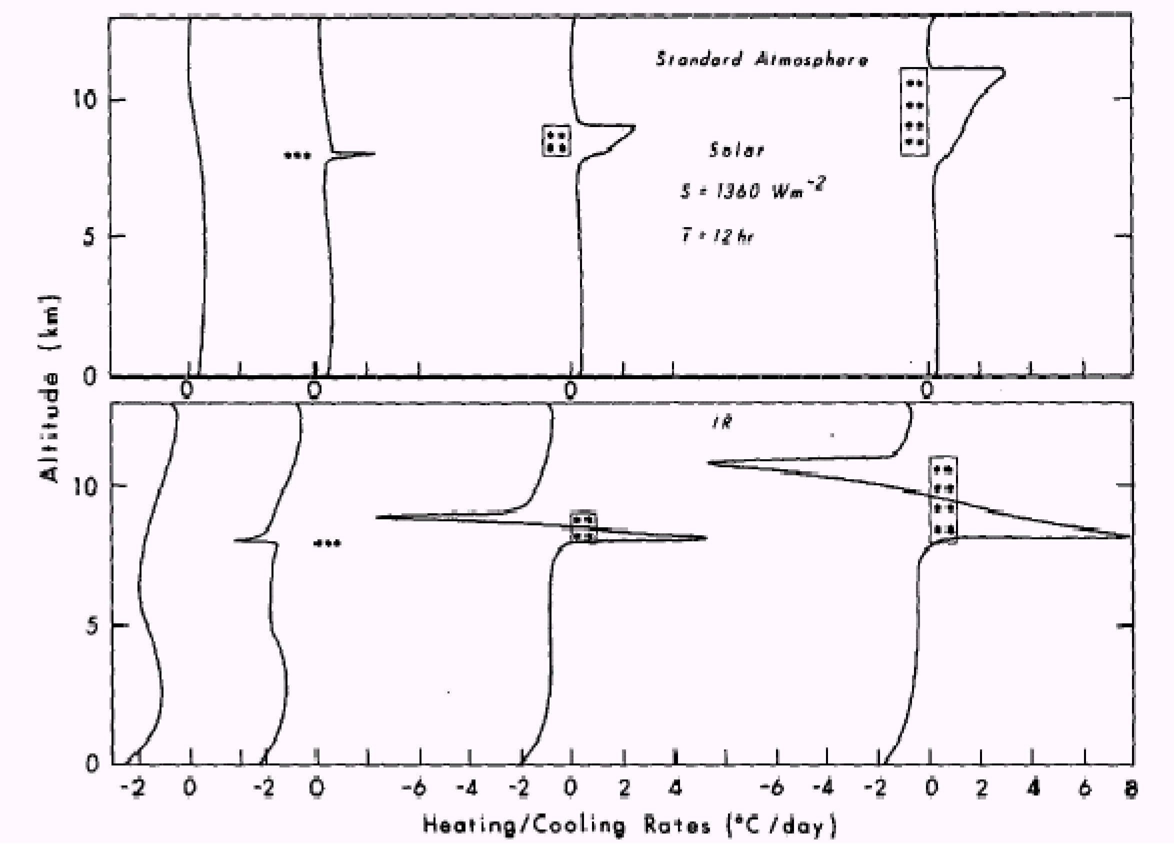


Figure 23.2 Solar and IR radiative heating/cooling rates for clear sky and for a cirrus cloud with thickness of 0.1, 1 and 3 km. The cloud base is fixed at 8 km. Solar heating rates were calculated for a solar constant of 1360 W/m^2, surface albedo of 0.15, cosine of solar zenith angle 0.5 and solar time duration of 12 hours (from Liou, 1986).

3. Net radiative heating/cooling rates in an aerosol-laden atmosphere.

- Radiative heating/cooling rates in an aerosol-laden atmosphere depend on optical properties of aerosols and their vertical distribution, solar angle (for solar heating rates), surface albedo (for solar heating rates), and atmospheric conditions (e.g., presence of clouds)

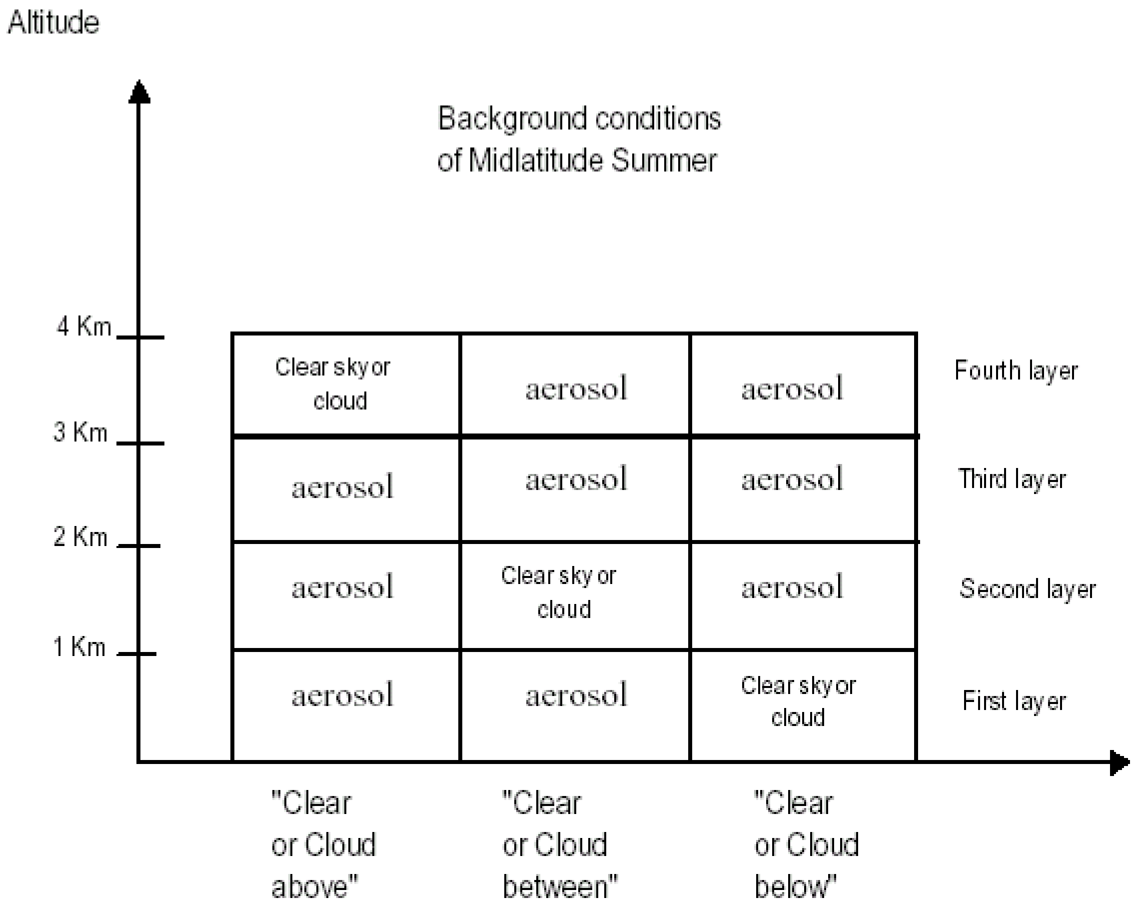


Figure 23.3 Schematic representation of the aerosol-cloud/clear sky vertical distribution for calculations of heating/cooling rates shown in figures 23.5-23.7

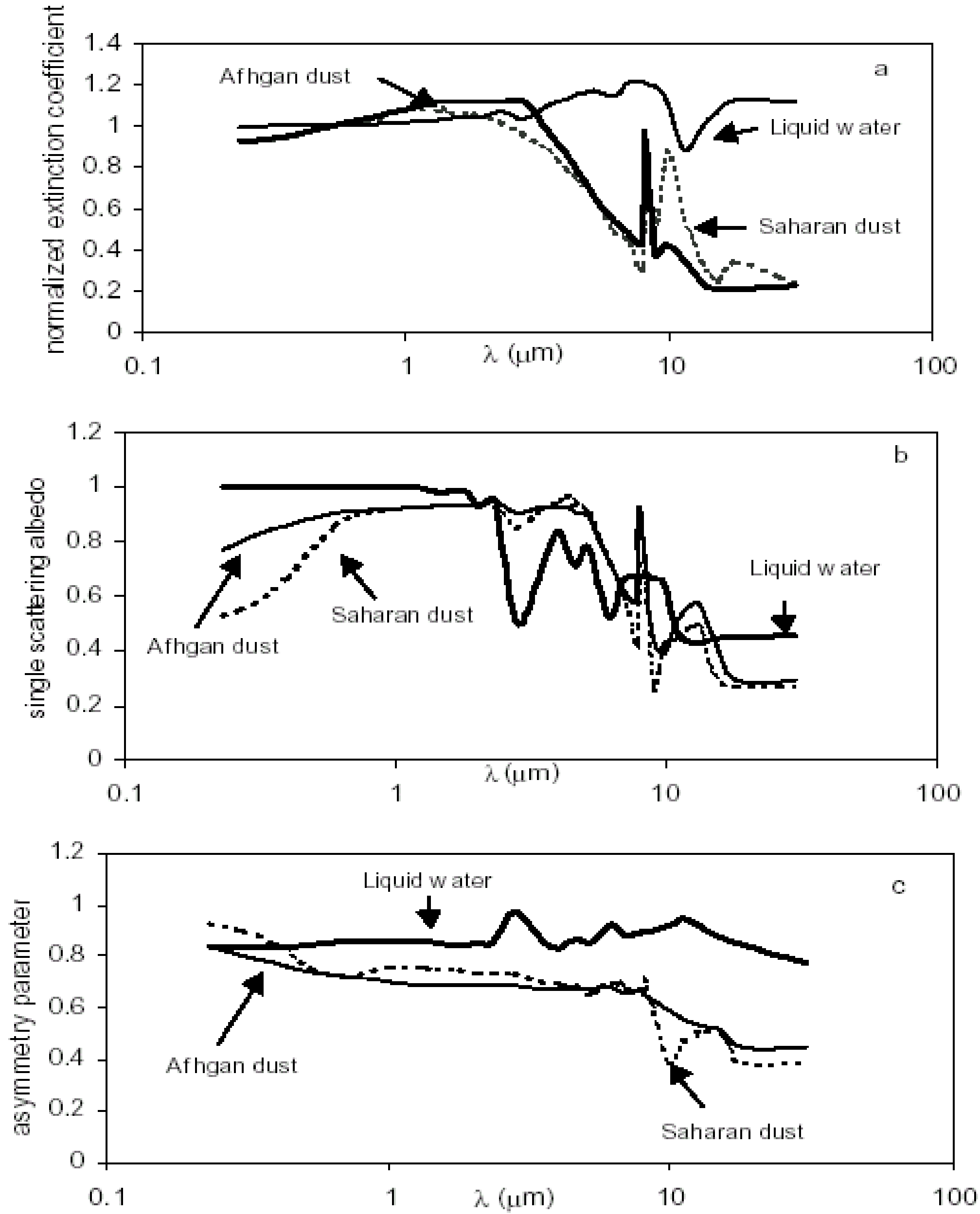


Fig. 23.4. Spectra of (a) normalized extinction coefficient βe(λ)/ βe(0.5μm), (b) single scattering albedo, ω_0, and (c) asymmetry parameter, g, defined for Saharan, Afgan dust models, and marine stratus cloud (Quijano and Sokolik, 2003).

Note: Saharan dust has lower values of single scattering albedo in visible part of solar spectrum

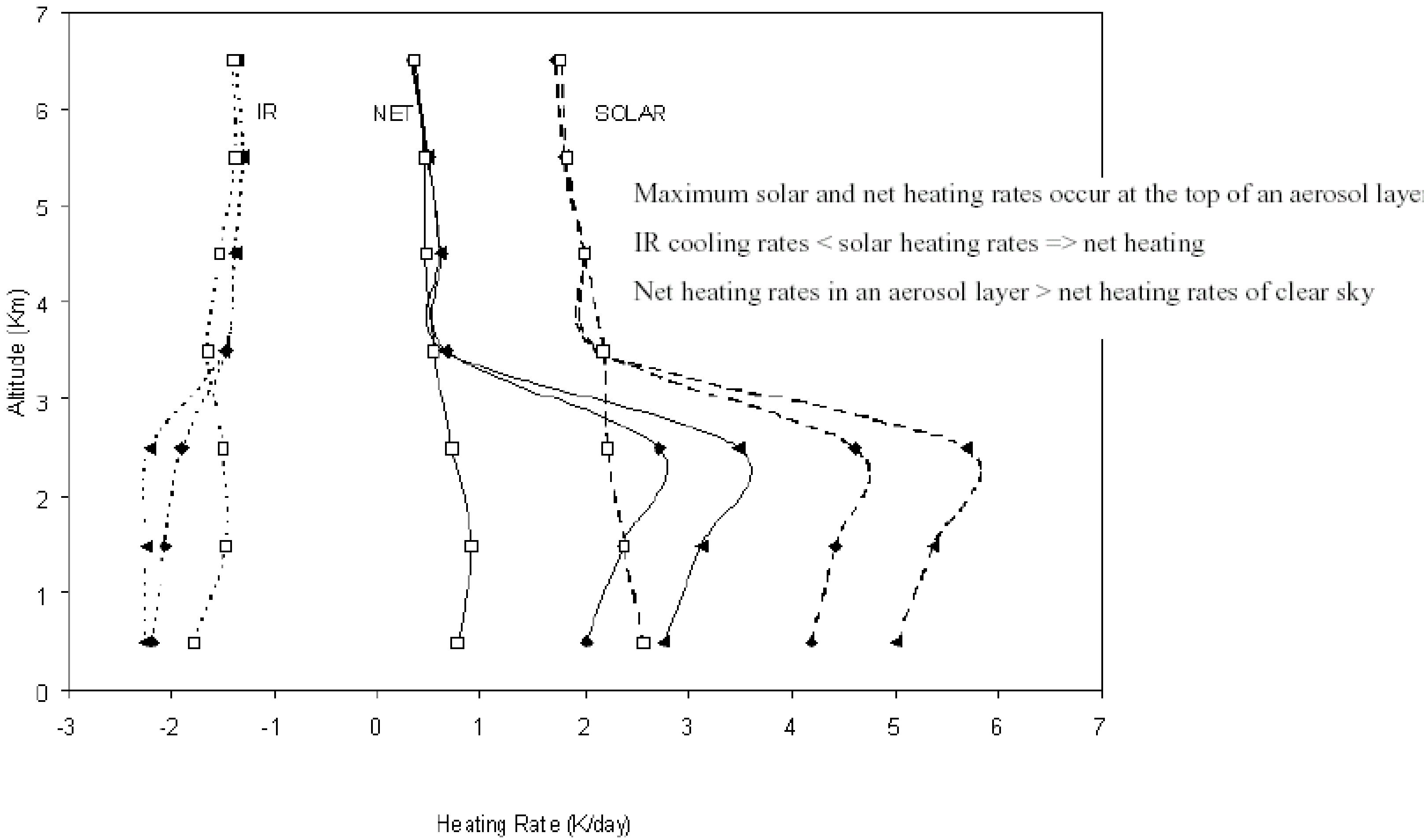


Figure 23. 5 Solar (long-dashed lines), infrared (short-dashed lines), and net (solid lines) radiative heating rates of Saharan and Afghan dust and for clear sky, over the desert (r_s=0.3) at μo = 0.8; open squares are for clear sky; triangles are for Saharan dust; diamonds are for Afghan dust; "Clear above" and τ_{dust} (0.5 μm) = 0.5 (Quijano and Sokolik).

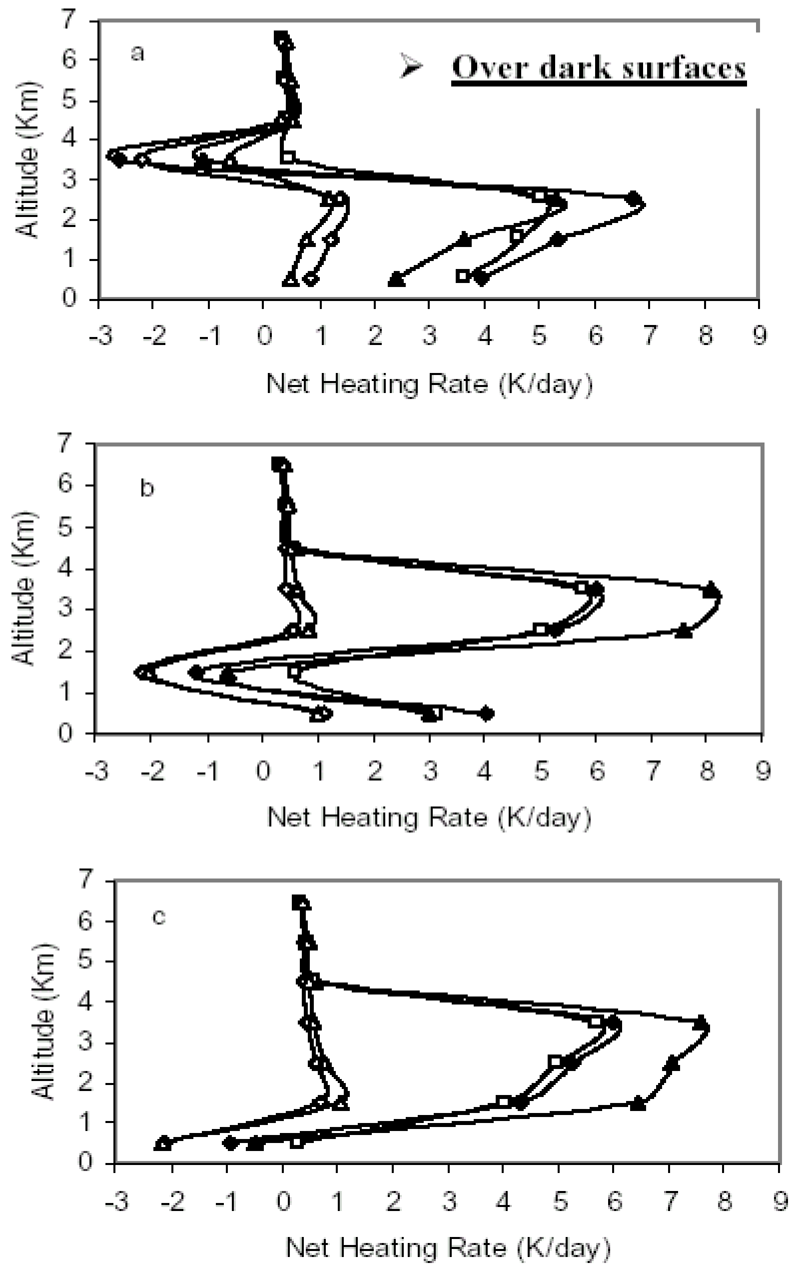


Fig. 23.6. Net radiative heating rates by dust and cloud <u>over ocean</u> at μ_0=0.8 for (a) "Clear or Cloud above", (b) "Clear or Cloud between", and (c) "Clear or Cloud below"; open diamonds are for "Only Thin Cloud"; open triangles are for "Only Thick Cloud"; open squares are for " Only Dust"; solid diamonds are for "Dust and Thin Cloud"; solid triangles are for "Dust and Thick Cloud"; Saharan dust and τ_{dust} (0.5 µm)=1. (Quijiano and Sokolik, 2003).

➢ **Over bright surfaces**

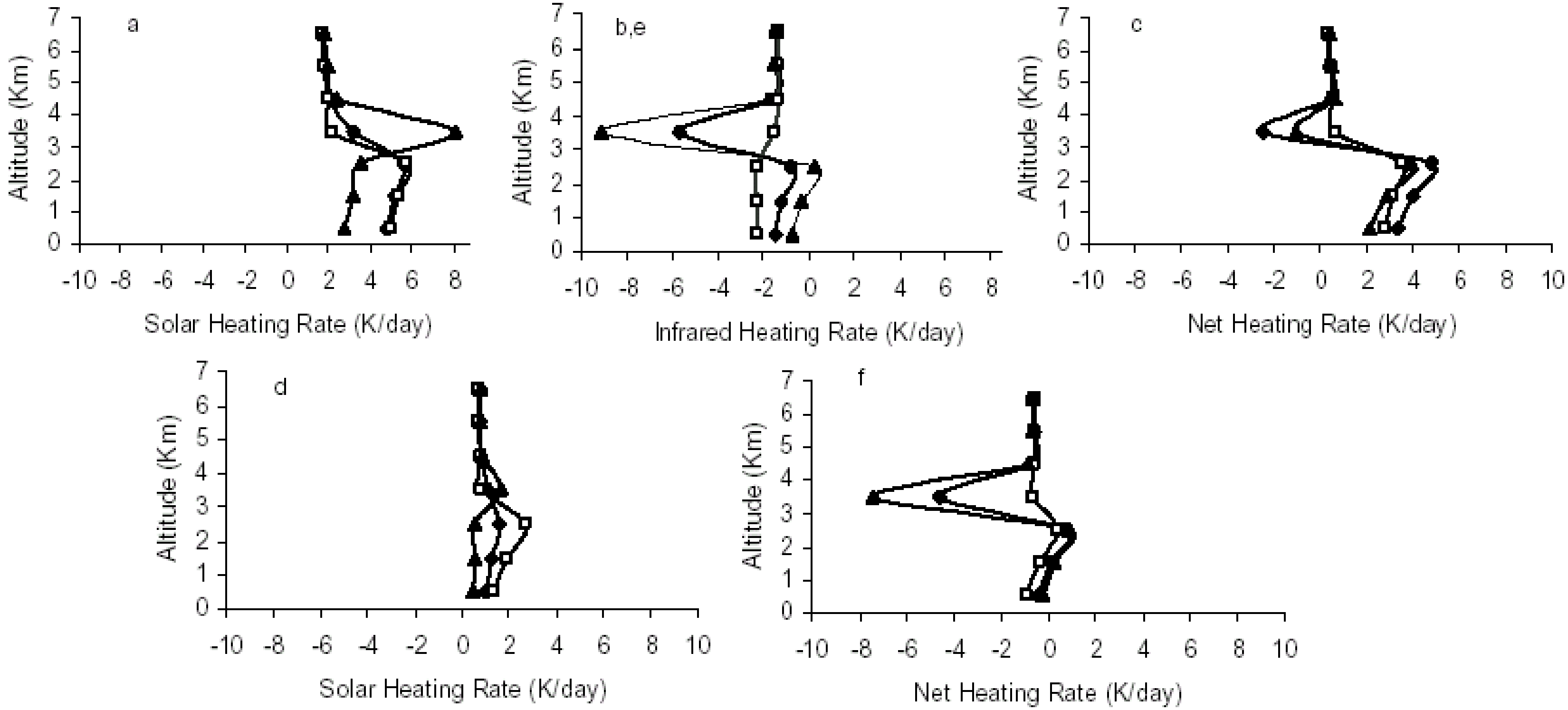
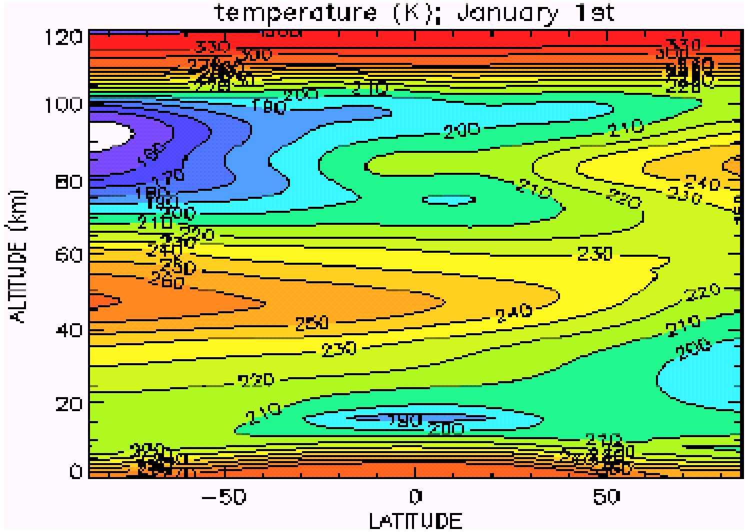
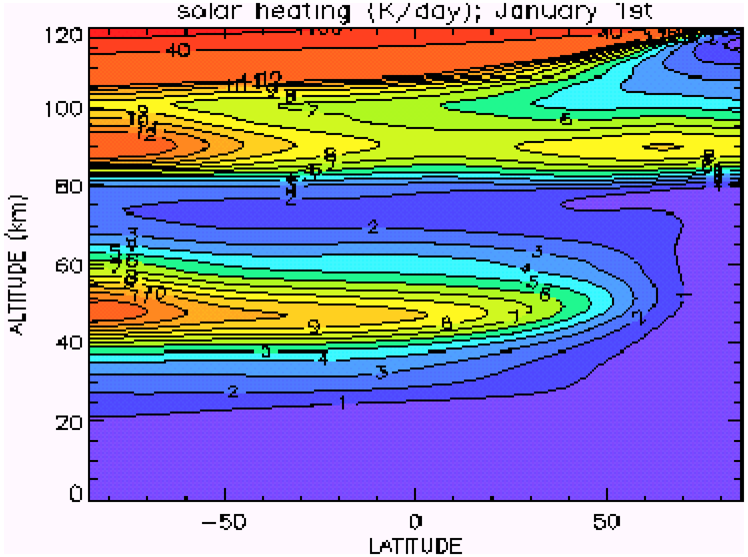
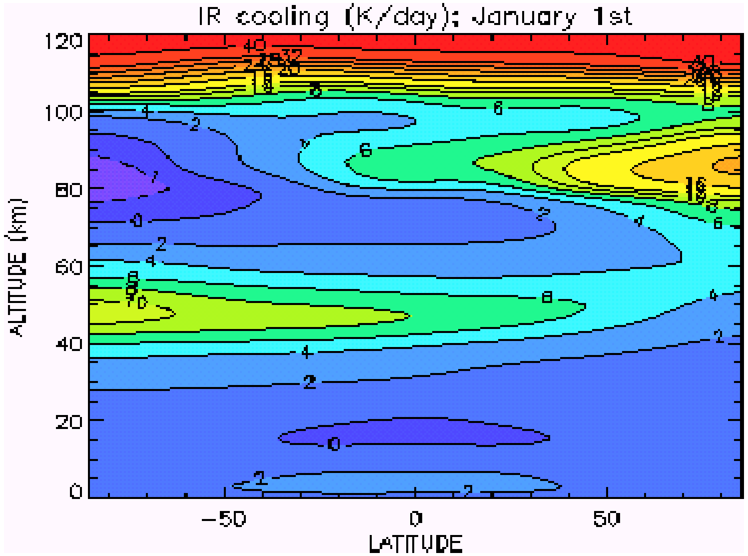


Figure 23.7 Radiative heating rates over the desert (r_s=0.3) of (a) solar, (b) infrared, and (c) net at μo = 0.8 and of (d) solar, (e) infrared, and (f) net at μo = 0.25; open squares are for "Clear above", diamonds are for "Thin cloud above"; triangles are for "Thick cloud above"; Saharan dust, and τ_{dust} (0.5 μm) = 0.5 (Quijano and Sokolik).

4. Global distribution of radiative heating/cooling rates.







SOCRATES (Simulation of Chemistry, Radiation, and Transport of Environmentally important Species) is the NCAR interactive chemical dynamical radiative 2-D model (http://acd.ucar.edu/models/SOCRATES/socrates/socrates1.html)